



Bureau International des Poids et Mesures

Benefits of the IGS-BIPM cooperation in international time keeping

E. F. Arias



IGS Workshop 2010

Newcastle upon Tyne (UK), 28 June – 2 July 2010

Outline

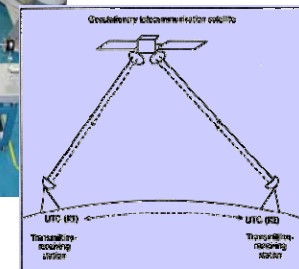
- Quicklook at the BIPM responsibilities and achievements
- The IGS-BIPM common interests and connexion
- Time transfer, an essential tool for international time keeping
- Use of the IGS products for time transfer in TAI
- Future

BUREAU INTERNATIONAL DES POIDS ET MESURES

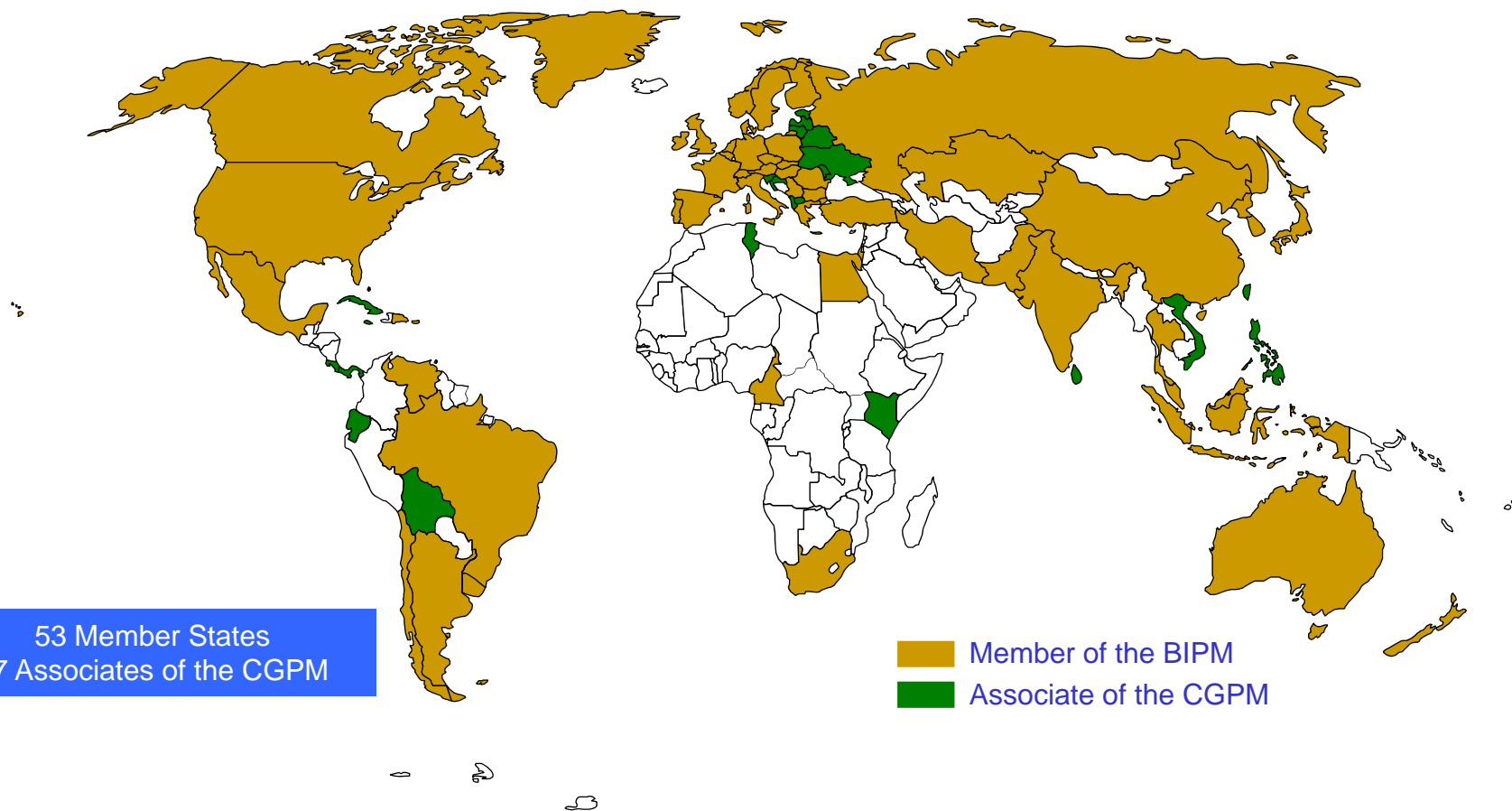
It has headquarters near Paris, France. It is financed jointly by the Member States and Associates, and operates under the exclusive supervision of the CIPM.

Its mandate is to provide the basis for a single, coherent system of measurements throughout the world, traceable to the International System of Units (SI). This task takes many forms, from direct dissemination of units (as in the case of mass and time) to coordination through international comparisons of national measurement standards.

It has an international staff of over 70 and its status vis-à-vis the French Government is similar to that of other intergovernmental organizations.



BIPM Membership



CIPM Consultative Committees related to TFG work

- ✓ CCTF (Consultative Committee for Time and Frequency)
 - ✓ Reference time scales TAI, UTC, TT
 - ✓ IUGG, IAU, URSI, ITU-R, IGS are members
- ✓ CCM (Consultative Committee for Mass and Related Quantities)
 - ✓ Working Group on Gravimetry
- ✓ CCU (Consultative Committee for Units)
 - ✓ IAU, CODATA, ISO are members

Time

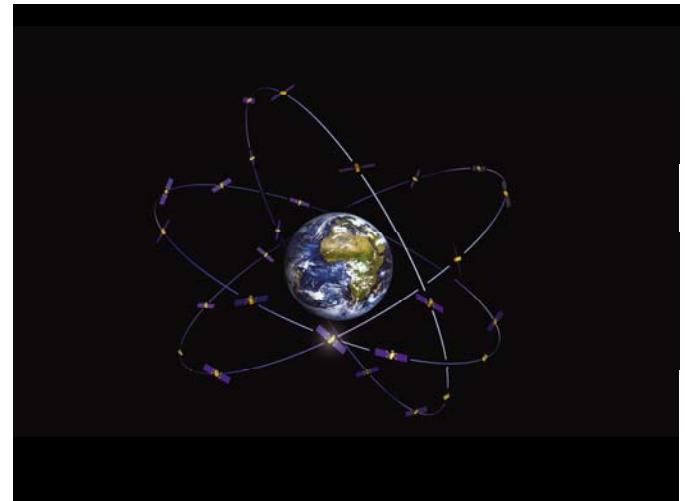
✓ Maintenance and dissemination of the international time scales TAI/UTC.

- ✓ Frequency stability is 0.4×10^{-15} @ 30-40 days
- ✓ Frequency accuracy is $\sim 10^{-15}$



✓ Coordination of activities in time laboratories contributing to TAI/UTC.

✓ Organization of the international network of time comparisons for TAI/UTC.



What do we need for TAI computation?

Time comparisons between real-time approximations to UTC: $UTC(k) - UTC(l)$

Section 1 of *BIPM Circular T*

CIRCULAR T 268
2010 MAY 07, 14h UTC

ISSN 1143-1393

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1 - Coordinated Universal Time UTC and its local realizations UTC(k). Computed values of $[UTC-UTC(k)]$ and uncertainties valid for the period of this Circular. From 2009 January 1, 0h UTC, $TAI-UTC = 34$ s.

Date 2010	0h UTC	MAR 29	APR 3	APR 8	APR 13	APR 18	APR 23	APR 28	Uncertainty/ns		
MJD		55284	55289	55294	55299	55304	55309	55314	u_A	u_B	u
Laboratory k		$[UTC-UTC(k)]/ns$									
ADS (Borowiec)		-10.2	-8.3	-3.4	-2.2	-0.3	-0.2	-0.4	1.5	5.1	5.3
APL (Laurel)		-2.7	-1.8	-2.9	-2.8	-2.0	-2.7	-1.3	1.5	5.0	5.2
AUS (Sydney)		227.7	206.4	185.2	166.8	160.0	144.4	128.8	0.3	5.0	5.1
BEV (Wien)		55.5	47.0	45.7	35.9	26.3	27.2	30.1	1.5	3.1	3.5
BIM (Sofiya)		-6781.1	-6768.6	-6762.4	-6755.4	-6759.2	-6751.6	-6739.6	2.0	7.1	7.3
BIRM (Beijing)		-10173.8	-10212.2	-10255.0	-10298.3	-10346.1	-10378.6	-10414.1	2.0	20.0	20.1
BY (Minsk)		52.3	60.1	70.2	-24.7	-23.0	-21.2	-20.0	2.0	7.1	7.3
CAO (Cagliari)		-4097.4	-4117.2	-4128.8	-4141.4	-4141.0	-4158.1	-4193.5	1.5	7.0	7.2
CH (Bern)		-2.7	-4.5	-3.4	-3.6	-4.7	-6.1	-5.9	0.6	1.4	1.5
CNM (Queretaro)		-9.2	-10.3	-2.6	-1.1	7.4	15.5	19.5	2.5	5.1	5.7

Frequency comparisons: for primary frequency standards (steering TAI frequency)

Section 4 of *BIPM Circular T*
Generally obtained by differencing time comparisons

Standard	Period of Estimation	d	u_A	u_B	$u_{1/Lab}$	$u_{1/TAI}$	u	Ref(u_B)	$u_B(Ref)$	Note
PTB-CS1	55284 55314	-5.21	6.00	8.00	0.00	0.13	10.00	T148	8.	(1)
PTB-CS2	55284 55314	0.23	3.00	12.00	0.00	0.13	12.37	T148	12.	(1)
NIST-F1	55274 55299	6.38	0.37	0.31	0.19	0.46	0.69	T214	0.35	(2)
SYRTE-JPO	55284 55314	7.38	0.61	6.30	0.30	0.46	6.35	T160	6.30	(3)
SYRTE-F01	55284 55314	4.84	0.30	0.40	0.11	0.46	0.69	T227	0.72	(4)
SYRTE-F02	55284 55309	5.58	0.30	0.39	0.11	0.54	0.74	T227	0.65	(4)

Notes:
 (1) Continuously operating as a clock participating to TAI
 (2) Report 28 APR. 2010 by NIST
 (3) Report 04 MAY. 2010 by LNE-SYRTE
 (4) Report 05 MAY. 2010 by LNE-SYRTE

IGS-BIPM (1)

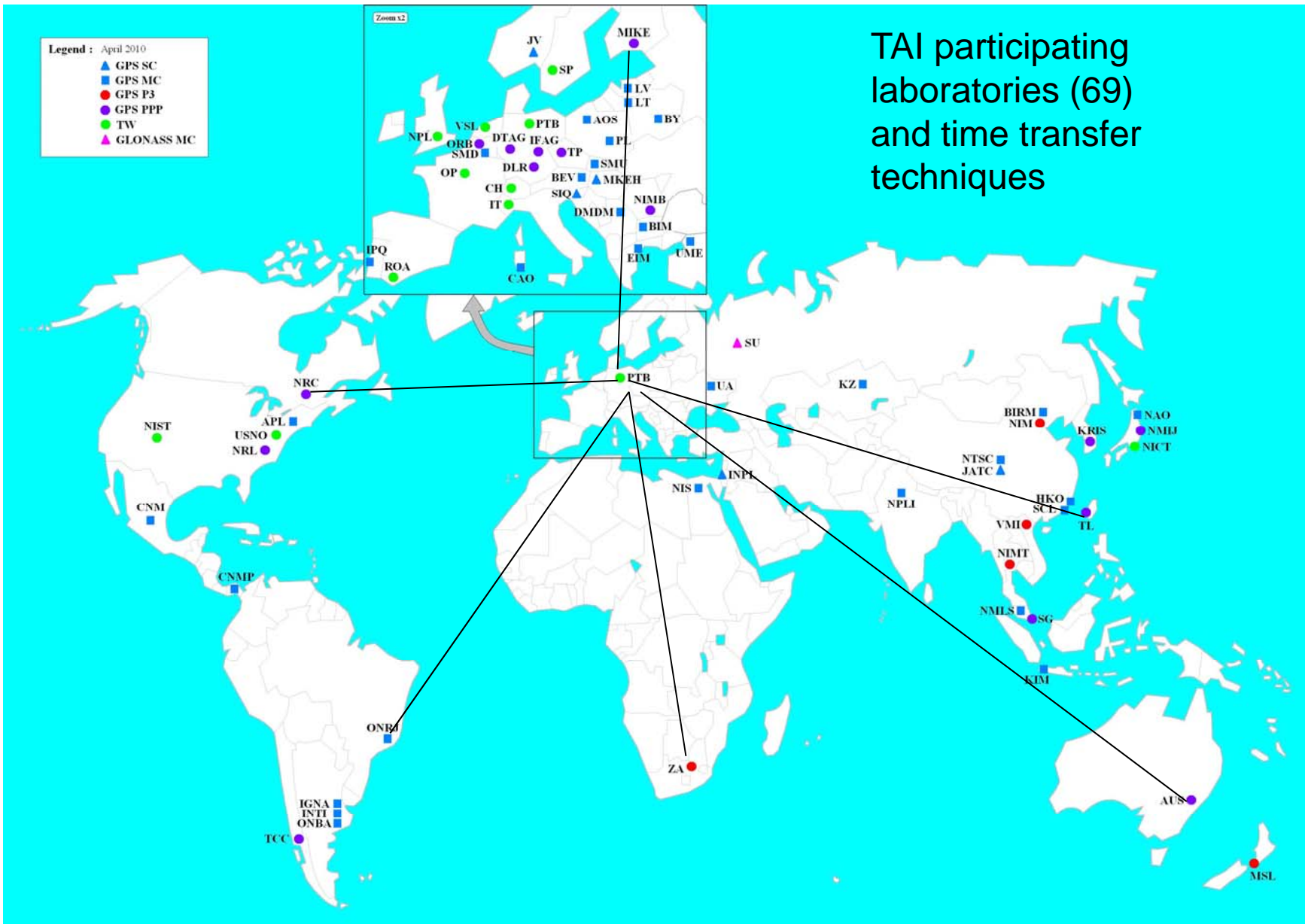
- **Projects/actions of common interest**
 - IGS/BIPM Pilot Project to study accurate time and frequency comparisons using GPS phase and code measurements (1999-2003)
 - IGS working group on clock products, with BIPM participation
 - IAG, GGOS
 - Actions within the International Committee for GNSS (ICG)
 - WG D, Task Forces on
 - Time references,
 - Geodetic references

IGS-BIPM (2)

- Official representation
 - BIPM is observer in the IGS Governing Board
 - IGS is a member of the Consultative Committee for Time and Frequency (CCTF)
- Fluid communication between individuals for technical issues

IGS-BIPM (3)

- **Production of TAI**
 - GPS C/A Common views (in use until mid 2006)
 - IGS precise orbits
 - IGS iono maps
 - GPS P3 (since 08/2003)
 - IGS precise orbits
 - GPS all-in-view (since 09/2006)
 - IGS precise orbits
 - IGS iono maps
 - IGS clock products
 - IGST (instability 10^{-15} @ 1 day)
 - GPS PPP (since 09/2009) – IGS/BIPM Pilot Project
 - GLONASS Common views (since 11/2009)
 - IGS-ESA precise orbits
 - IGS iono maps



TAI participating laboratories (69) and time transfer techniques

Time transfer techniques in use

GNSS, mostly GPS

- Code measurements
 - C/A (1.575 GHz, 1 Mchip/s)
 - P1/2 (1.575/1.227 GHz, 10Mchip/s)
- Phase + code measurements
 - L1/2, P1/2 (1.575/1.227 GHz)

Achievable uncertainty: $< \sim 1/\text{few ns}$
Limited by
Multi-path reflections
Transmission delay in troposphere

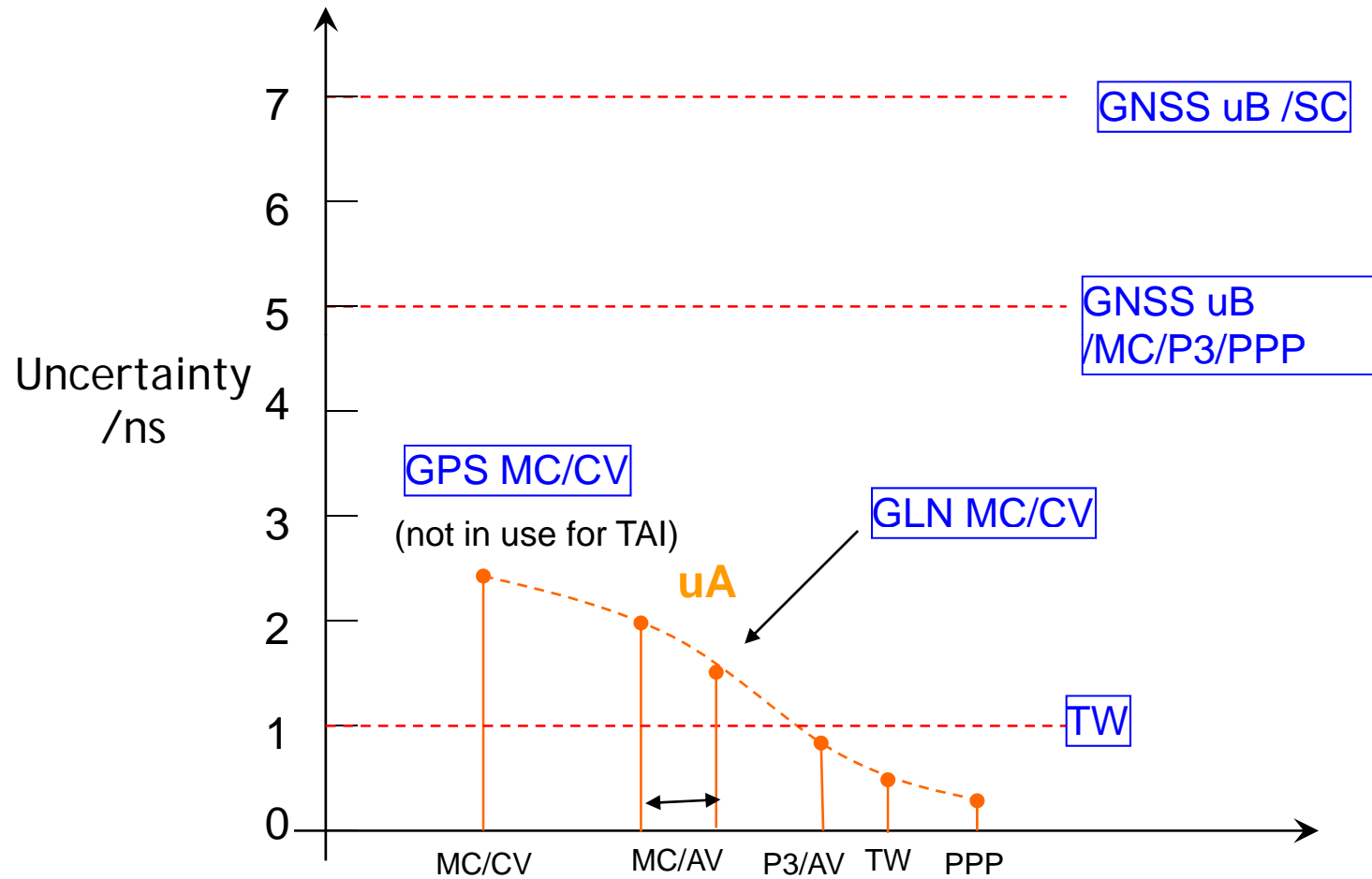
Achievable uncertainty: (few) 0.1 ns
Limited by
Phase ambiguity resolution
Various effects @ $< 0.1 \text{ ns level}$

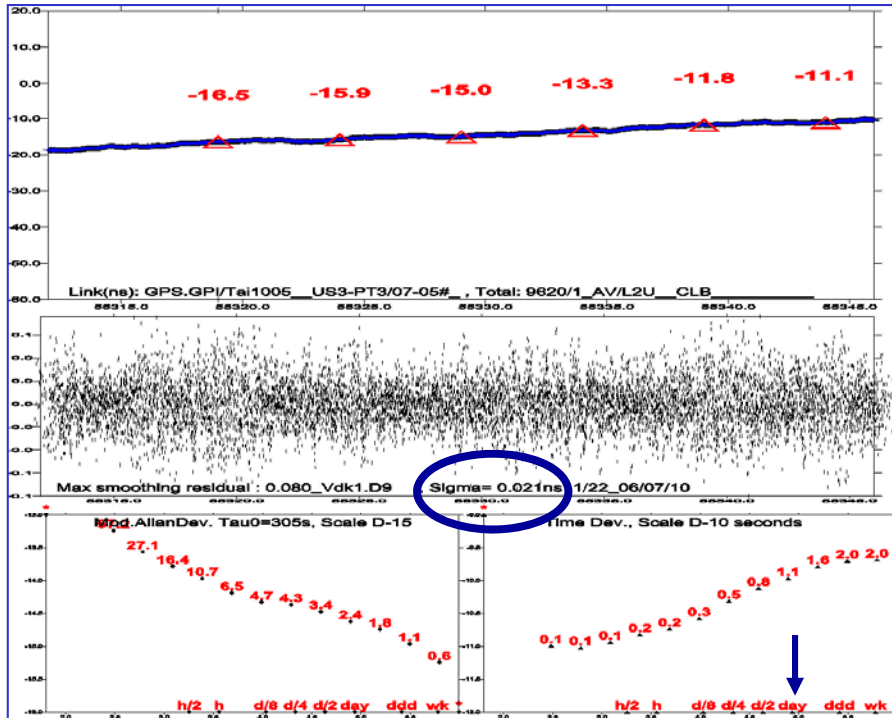
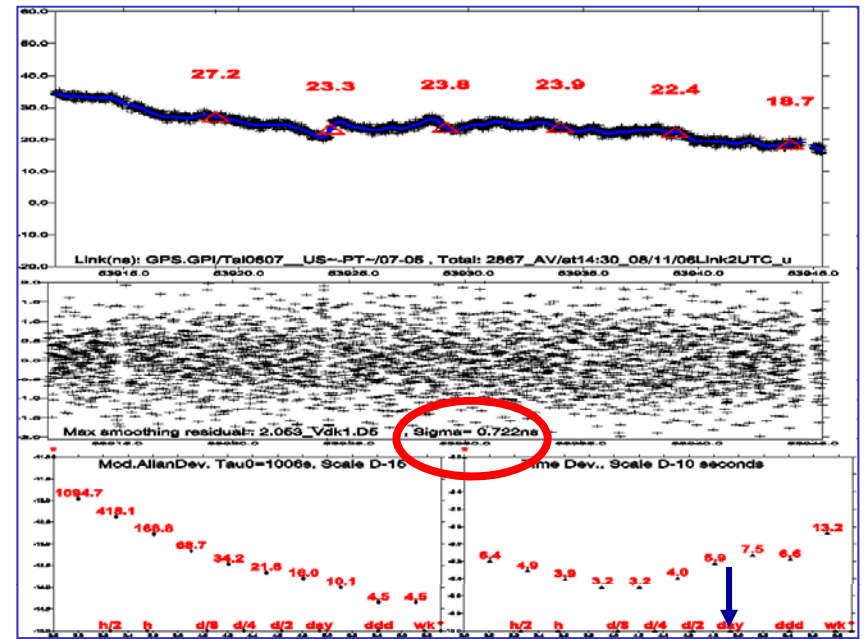
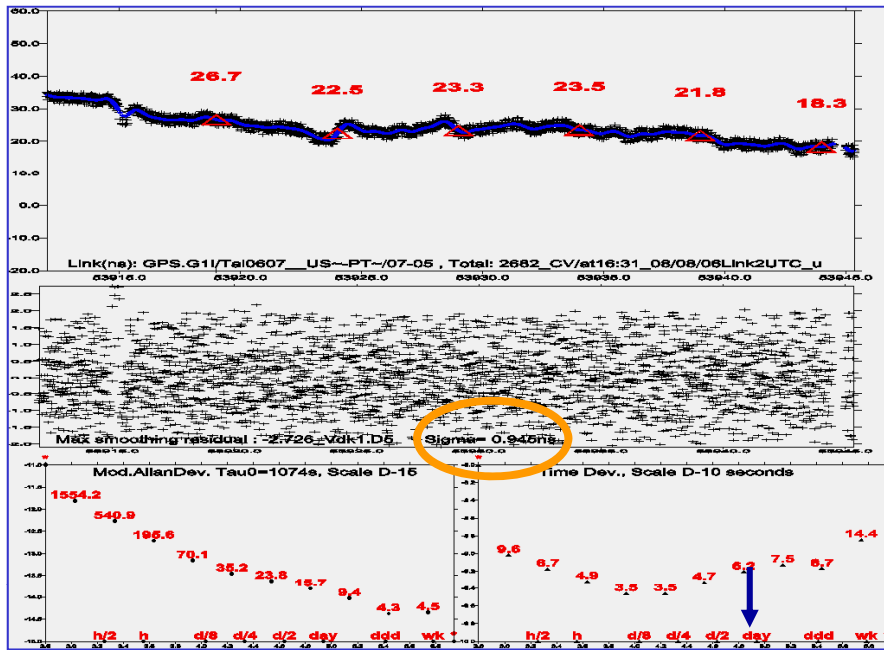
TW satellite time transfer

- Code measurements
 - Ku band (14 GHz, 1 Mchip/s))

Achievable uncertainty: (few) 0.1 ns
Limited by
Effects on satellite equipment

Uncertainty of UTC time transfer (calibrated equipment only)





P3 CV

$\sigma = 0.940 \text{ ns}$

P3 AV

$\sigma = 0.722 \text{ ns}$

PPP

$\sigma = 0.021 \text{ ns}$



What (more) shall we use tomorrow?

GNSS: GLONASS, Galileo

- Phase + code measurements
New frequencies, new codes, more satellites

Significant improvement
Expected but not one order of magnitude

TW time transfer (dedicated payloads)

- Phase + Code measurements

Dedicated payloads should allow
order of magnitudes
improvements

Fiber links

Progressing so fast that it is
difficult to forecast

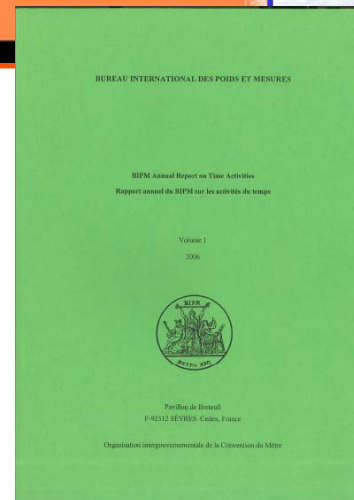
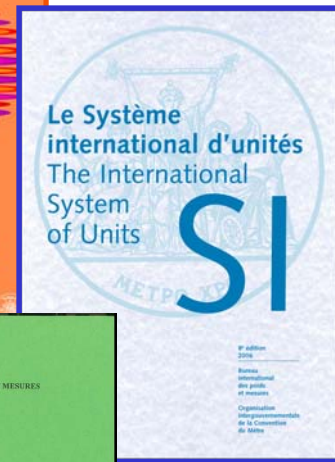
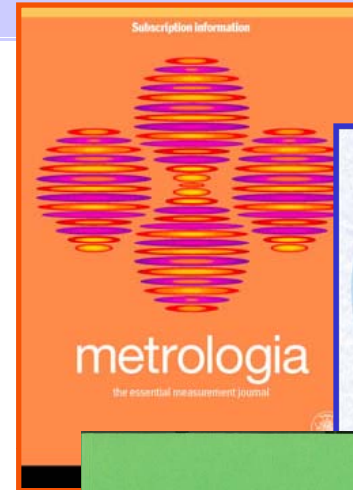
PUBLICATIONS

Metrologia is an international journal dealing with the scientific aspects of metrology.

The SI Brochure.

The BIPM disseminates the time scales and gives traceability to UTC to participating laboratories through the monthly BIPM Circular T.

The Annual report on Time Activities gives definitive results and complete information on TAI and UTC.



ISSN 1043-1395

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Métrologia - From 2006 January 1, on UTC, 'TAI-UTC' is 33 s.

EP 0	FEB 13	FEB 18	FEB 23	FEB 28	Uncertainties	Notes
54504	54509	54514	54519	54524	u_1	u_2
0.1	1.1	3.2	3.2	2.9	1.5	5.1
117.9	112.4	128.1	126.0	124.1	1.5	5.1
460.2	460.2	460.2	460.2	460.2	1.5	5.1
1027.5	1027.5	1027.5	1027.5	1027.5	1.5	5.1
1924.8	1924.8	1924.8	1924.8	1924.8	1.5	5.1
2832.1	2832.1	2832.1	2832.1	2832.1	1.5	5.1
3739.4	3739.4	3739.4	3739.4	3739.4	1.5	5.1
4646.7	4646.7	4646.7	4646.7	4646.7	1.5	5.1
5554.0	5554.0	5554.0	5554.0	5554.0	1.5	5.1
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9183.2	9183.2	9183.2	9183.2	9183.2	1.5	5.1
10090.5	10090.5	10090.5	10090.5	10090.5	1.5	5.1
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33750.0	33750.0	33750.0	33750.0	33750.0	1.5	5.1
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95630.0	95630.0	95630.0	95630.0	95630.0	1.5	5.1
96540.0	96540.0	96540.0	96540.0	96540.0	1.5	5.1
97450.0	97450.0	97450.0	97450.0	97450.0	1.5	5.1
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102910.0	102910.0	102910.0	102910.0	102910.0	1.5	5.1
103820.0	103820.0	103820.0	103820.0	103820.0	1.5	5.1
104730.0	104730.0	104730.0	104730.0	104730.0	1.5	5.1
105640.0	105640.0	105640.0	105640.0	105640.0	1.5	5.1
106550.0	106550.0	106550.0	106550.0	106550.0	1.5	5.1
107460.0	107460.0	107460.0	107460.0	107460.0	1.5	5.1
108370.0	108370.0	108370.0	108370.0	108370.0	1.5	5.1
109280.0	109280.0	109280.0	109280.0	109280.0	1.5	5.1
110190.0	110190.0	110190.0	110190.0	110190.0	1.5	5.1
111100.0	111100.0	111100.0	111100.0	111100.0	1.5	5.1
112010.0	112010.0	112010.0	112010.0	112010.0	1.5	5.1
112920.0	112920.0	112920.0	112920.0	112920.0	1.5	5.1
113830.0	113830.0	113830.0	113830.0	113830.0	1.5	5.1
114740.0	114740.0	114740.0	114740.0			



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